The NUbots Team Description Paper 2015

Josiah Walker, Trent Houliston, Brendan Annable, Alex Biddulph, Jake Fountain, Mitchell Metcalfe, Anita Sugo, Monica Olejniczak, Stephan K. Chalup, Robert A.R. King, Alexandre Mendes, and Peter Turner

Newcastle Robotics Laboratory
School of Electrical Engineering & Computer Science
Faculty of Engineering and Built Environment
The University of Newcastle, Callaghan 2308, Australia
Contact: stephan.chalup@newcastle.edu.au
Homepage: http://robots.newcastle.edu.au

Abstract. The NUbots are an interdisciplinary RoboCup team from The University of Newcastle, Australia. The team has a history of strong contributions in the areas of machine learning and computer vision. The NUbots have participated in RoboCup leagues since 2002, placing first several times in the past. In 2014 the NUbots also partnered with the University of Newcastle Mechatronics Laboratory to participate in the RobotX Marine Robotics Challenge, which resulted in several new ideas and improvements to the NUbots vision system for RoboCup. This paper summarizes the history of the NUbots team, describes the roles and research of the team members, gives an overview of the NUbots' robots, their software system, and several associated research projects.

1 Introduction

The NUbots team, from the University of Newcastle, Australia, competed in the Four Legged League from 2002-2007, within the Standard Platform League from 2008-2011 and subsequently within the Kid-Size Humanoid league since 2012. The NUbots have had a strong record of successes, twice achieving a first place; in 2006 in Bremen, Germany, and, again in 2008 as part of the NUManoid team in Suzhou, China.

The central goal of the NUbots is to compete in RoboCup at a high level by applying current research. The research projects associated with the NUbots team provide unique research and learning opportunities for both undergraduate and postgraduate students in areas related to autonomy and human interaction. Our mission is to contribute to a responsible development and application of robotics. The NUbots also align with the Newcastle Robotics Laboratory which aims to develop and program robots that can support humans not only for routine, challenging, or dangerous tasks, but also to improve quality of life through personal assistance, companionship, and coaching. Some of our projects therefore emphasise anthropocentric and biocybernetic aspects in robotics research [14,33,21,36].

2 Commitment to RoboCup 2015

The NUbots commit to participation at RoboCup 2015 upon successful qualification. We also commit to provision of a person, with sufficient knowledge of the rules, available as referee during the competition.

3 History of the NUbots' participation at RoboCup

The NUbots participated for the first time at RoboCup 2002 in Fukuoka in the Sony Four-Legged League (3rd place). Since then the team has a strong history of competition and success in the RoboCup SPL/Four-Legged League, obtaining many top three placements and winning the title in 2006 and 2008. In 2013 the NUbots missed out on a place in the quarter finals of the Kidsize League by only one goal. We hope to improve on this in 2015.

The NUbots joined the Kidsize League in 2012 with the DARwIn-OP robots, and ported their SPL codebase to the new platform. The NUbots retained a robust and fast vision and localisation system from the SPL, and ported the B-human NAO walk to the DARwIn-OP for 2012-2013. In 2013 the NUbots presented a curiosity based reinforcement learning approach to gaze planning, which was used with on-line learning for all games during the competition.

4 Background of the NUbots Team Members

- *Brendan Annable* is a 4th year undergraduate honours student studying Software Engineering and is the team's leader. His interests include developing the team's real-time visual debugging systems and other research areas in machine intelligence, computer graphics and GPGPU computing.
- *Trent Houliston* is studying for a Doctorate of Philosophy in Software Engineering in Software Architecture for Robotics and Artificial Intelligence and is the team's head of research. He designed and implemented the new architecture for the robots, and aided in the development of many of the components.
- *Jake Fountain* is studying for a Doctorate of Philosophy in Computer Science. Jake has undergraduate degrees in mathematics and science, majoring in physics, with Honours in Computer Science [16]. His main interests lie in virtual reality and robotics.
- *Josiah Walker* is studying for a Doctorate of Philosophy in Computer Science in Large Scale Search and Robotics. He works on robot behaviour and machine learning for various NUbot systems. He has been the NUbots team leader for 2013-2014.
- *Mitchell Metcalfe* is an honours year student studying Computer Science. Mitchell completed undergraduate degrees in Mathematics and Computer Science in 2014. He contributes to the NUbots' localisation system, and is interested in SLAM methods.

- *Anita Sugo* is a third year undergraduate student studying a combined degree in Mathematics and Science. She is interested in the mathematics used in robotics.
- *Monica Olejniczak* is a 4th year undergraduate honours student studying Software Engineering. She has contributed to the NUbots' configuration system and is interested in developing debugging tools.
- *Alex Biddulph* is a 5th year undergraduate student studying Computer Engineering and Computer Science. He is currently working to improve the vision system and develop an alternative controller platform for the Darwin. He is interested in embedded systems and the melding of software and hardware (electronics) and programmable hardware.
- *Peter Turner* is technical staff in the School of Electrical Engineering and Computer Science. Peter provides hardware support and assists the team with physical robot design upgrades.
- *Dr. Robert King* is a Lecturer in Statistics at the University of Newcastle. His research focus is on flexibly-shaped distributions, statistical computing and Bayesian knowledge updating. He joined the NUbots in 2004 and has developed a special interest in the RoboCup rules and refereeing.
- *Dr. Alexandre Mendes* is deputy head of the Newcastle Robotics Lab. He is a Senior Lecturer in Computer Science and Software Engineering. He joined the group in September 2011 and his research areas are algorithms and optimisation.
- *A/Prof. Stephan Chalup* is the head of the Newcastle Robotics Lab. He is an Associate Professor in Computer Science and Software Engineering. He is one of the initiators of the University of Newcastle's RoboCup activities since 2001. His research area is machine learning and anthropocentric robotics.

We also acknowledge the valuable input of colleagues from the Newcastle Robotics Laboratory, team members of previous years and the Interdisciplinary Machine Learning Research Group (IMLRG) in Newcastle, Australia. Details are linked to the relevant webpages at `www.robots.newcastle.edu.au`.

5 Hardware and Software Overview

The NUbots use the DARwIn-OP robot with foot sensors. The team has seven of these robots that are of the standard design with the exception of a slightly reduced foot size. The team also hopes to field modified DARwIn-OP robots consisting of a full HD camera, an ODroid-XU computer and an updated motor communications board as a part of a student project.

The NUbots team's major research focus is on using machine learning methods within the software systems of the robot to achieve increased performance and autonomy [13]. The current NUbots software source is available from [29] and is covered under the GPL. This code includes associated toolkits for building and deploying the software. Our software is designed to work on multiple robotic platforms, and all of the individual modules have been designed to be

easily used in other systems. The flexibility of our approach has been demonstrated in a deployment of the NUbots vision system on a marine platform [10].

Following development of a new software system in 2014, the NUbots are now focusing on current and emerging challenges within the RoboCup Kid-size League. These include robust, adaptable image segmentation; generic ball detection; and improving the architecture of current walk engines to allow for more rapid experimentation and improvement. The NUbots software is designed to allow new teams and team members to easily understand and innovate on existing code, and is made freely available to encourage research and innovation.

6 Acknowledgement of Use of Code

The NUbots DARwIn-OP robots use a walk engine based on the 2013 Team Darwin code release. We acknowledge the source of this code. The NUbots have ported this code to C++ and restructured the logic, making numerous structural and technical changes since.

7 Hardware Enhancements since RoboCup 2014

At RoboCup 2014 we trialled rapid prototyping for a new head design for the Darwin-OP robots to fit upgraded Logitech C920 cameras. Since this time we have been improving designs and readying for an open source release once remaining issues are resolved. We field these otherwise standard Darwin-OP robots under the name NU-Darwin.

We have been partnering with Kontron Australia to develop more powerful embedded pc boards in order to upgrade our capabilities and deploy new robotics platforms. This upgrade will see higher quality accelerometers and gyroscopes and more hardware communications channels added to the robots, as well as an upgrade to a quad-core celeron platform with access to OpenCL.

8 Research Areas

Robot Vision: Vision is one of the major research areas associated with the Newcastle Robotics Laboratory. Several subtopics have been investigated including object recognition, horizon determination, edge detection, model fitting and colour classification using ellipse fitting, convex optimisation and kernel machines. Recent work has resulted in a fully-autonomous method of colour look-up table adaptation for changing lighting conditions, allowing us to overcome one of the major limitations of the colour look-up table system. Publications are available e.g. from [5,6,20,30,32,19,15,7,10].

Localisation and Kalman Filters: Research on the topic of localisation focused on Bayesian approaches to robot localisation including Kalman Filter and particle filter based methods. We are interested in modifications of the Kalman

Filter to handle non-ideal information from vision, incorporate increased information from multiple agents, and effectively utilise non-unique objects.

Development of the Robot Bear: In a collaborative effort with the company Tribotix and colleagues in design, a bear-like robot (called Hykim) was developed [9]. It has a modular open platform using Dynamixel servos.

Biped Robot Locomotion: The improvement of walking speed and stability has been investigated by the NUbots for several years and on different platforms: On the AIBO robot we achieved one of the fastest walks at that time by walk parameter evolution [31,13]. On the Nao robot we improved existing walk engines by modifying the joint stiffnesses, or controller gains, [26,27,25]. The stiffnesses were selected through an iterative process to maximise the cost of transport. We investigated the application of Support Vector Machines and Neural Networks to proprioception data for sensing perturbations during pseudo quiet stance. Walk improvements have been primarily done via optimisation techniques [28], with recent improvements to our framework for online optimisation of bipedal humanoid locomotion. The use of spiking neural networks has been trialled in simulation [34]. Prior to RoboCup 2012 the walk engine developed by the leading SPL team BHuman [18] was ported to the DARwIn-OP platform, and a variety of optimisation techniques were developed and successfully applied to improve walking speed and stability of the DARwIn-OP‘[8]. Multi-agent walk optimisation is being developed for this year's competition.

Reinforcement Learning, Affective Computing and Robot Emotions: We investigate the feasibility of reinforcement learning or neurodynamic programming for applications such as motor control and music composition. Concepts for affective computing are developed in multidisciplinary projects in collaboration with the areas of architecture and cognitive science. The concept of emotion is important for selective memory formation and action weighting and continues to gain importance in the robotics community, including within robotic soccer. A number of projects in the Newcastle Robots Laboratory already address this topic [12,22,23,36,21].

Gaze analysis and head movement behavioural learning: We investigated methods for human and robot pedestrian gaze analysis in [24,35] as well as space perception, way finding and the detection and analysis of salient regions [3,2,4]. Recently we applied motivated reinforcement learning techniques to optimising head movement behaviour, providing a robust algorithm by which a robot learns to choose landmarks to localise efficiently during a soccer game [17]. This algorithm was used in competition at RoboCup 2013, and is in the process of being adapted for our new software architecture.

Manifold Learning: In several projects we investigate the application of nonlinear dimensionality reduction methods in order to achieve more understanding of, and more precise and efficient processing of, high-dimensional visual and acoustic data. [11,35].

Other new projects: Much work has been focused on the underlying software architecture and external utilities to enable flexibility and extensibility for future research. Projects undertaken include improving the configurability of the soft-

ware system via real-time configuration updates, development of a web-based online visualisation and debugging utility [1] and the application of software architectural principles to create a multithreaded event-based system with almost no run-time overhead. Some of this work is still in progress by new undergraduate students who have joined the team.

9 Related Research Concentrations

The *Interdisciplinary Machine Learning Research Group (IMLRG)* investigates different aspects of machine learning and data mining in theory, experiments and applications. The IMLRG's research areas include: Dimensionality reduction, vision processing, robotics control and learning, evolutionary computation, optimisation, reinforcement learning, and kernel methods. Links to publications can be found at the NUbots' webpage `http://robots.newcastle.edu.au/`

References

1. Brendan Annable, David Budden, and Alexandre Mendes. Nubugger: A visual real-time robot debugging system. In *RoboCup 2013: Robot Soccer World Cup XVII*, Lecture Notes in Artificial Intelligence (LNAI). Springer, 2014. accepted 8.5.2013.
2. Shashank Bhatia and Stephan K. Chalup. A model of heteroassociative memory: Deciphering surprising features and locations. In Mary L. Maher, Tony Veale, Rob Saunders, and Oliver Bown, editors, *Proceedings of the Fourth International Conference on Computational Creativity (ICCC 2013)*, pages 139–146, Sydney, Australia, June 2013.
3. Shashank Bhatia and Stephan K. Chalup. Segmenting salient objects in 3d point clouds of indoor scenes using geodesic distances. *Journal of Signal and Information Processing*, 4(3B):102–108, 2013.
4. Shashank Bhatia, Stephan K. Chalup, and Michael J. Ostwald. Wayfinding: a method for the empirical evaluation of structural saliency using 3d isovists. *Architectural Science Review*, 56(3):220–231, 2013.
5. D. Budden, S. Fenn, A. Mendes, and S. Chalup. Evaluation of colour models for computer vision using cluster validation techniques. In *RoboCup 2012: Robot Soccer World Cup XVI*, Lecture Notes in Computer Science. Springer, 2013.
6. D. Budden, S. Fenn, J. Walker, and A. Mendes. A novel approach to ball detection for humanoid robot soccer. In *Advances in Artificial Intelligence (LNAI 7691)*. Springer, 2012.
7. D. Budden and A. Mendes. Unsupervised recognition of salient colour for real-time image processing. In *RoboCup 2013: Robot Soccer World Cup XVII*. Springer, 2013.
8. D. Budden, J. Walker, M. Flannery, and A. Mendes. Probabilistic gradient ascent with applications to bipedal robot locomotion. In *Australasian Conference on Robotics and Automation (ACRA)*, 2013.
9. S. K. Chalup, M. Dickinson, R. Fisher, R. H. Middleton, M. J. Quinlan, and P. Turner. Proposal of a kit-style robot as the new standard platform for the four-legged league. In *Australasian Conference on Robotics and Automation (ACRA) 2006*, 2006.

10. Stephan K Chalup, Zhiyong Chen, Jamil Khan, Alexandre Mendes, and Christopher Renton. Developing an autonomous swarm of small helicopters: Controlling cooperative team behaviour for search and surveillance.
11. Stephan K. Chalup, Riley Clement, Joshua Marshall, Chris Tucker, and Michael J. Ostwald. Representations of streetscape perceptions through manifold learning in the space of hough arrays. In *2007 IEEE Symposium on Artificial Life*, 2007.
12. Stephan K. Chalup, Kenny Hong, and Michael J. Ostwald. Simulating pareidolia of faces for architectural image analysis. *International Journal of Computer Information Systems and Industrial Management Applications (IJCISIM)*, 2:262–278, 2010.
13. Stephan K. Chalup, Craig L. Murch, and Michael J. Quinlan. Machine learning with aibo robots in the four legged league of robocup. *IEEE Transactions on Systems, Man, and Cybernetics—Part C*, 37(3):297–310, May 2007.
14. Stephan K. Chalup and Michael J. Ostwald. Anthropocentric biocybernetic computing for analysing the architectural design of house facades and cityscapes. *Design Principles and Practices: An International Journal*, 3(5):65–80, 2009.
15. Madison Flannery, Shannon Fenn, and David Budden. Ransac: Identification of higher-order geometric features and applications in humanoid robot soccer. *arXiv preprint arXiv:1310.5781*, 2013.
16. Jake Fountain and Stephan K Chalup. Point of regard from eye velocity in stereoscopic virtual environments based on intersections of hypothesis surfaces. In *Artificial Life and Computational Intelligence*, pages 125–141. Springer, 2015.
17. Jake Fountain, Josiah Walker, David Budden, Alexandre Mendes, and Stephan K. Chalup. Motivated reinforcement learning for improved head actuation of humanoid robots. In *RoboCup 2013: Robot Soccer World Cup XVII*, Lecture Notes in Artificial Intelligence (LNAI). Springer, 2014. accepted 8.5.2013.
18. Colin Graf and Thomas Röfer. A closed-loop 3d-lipm gait for the robocup standard platform league humanoid. In Enrico Pagello, Changjiu Zhou, Sven Behnke, Emanuele Menegatti, Thomas Röfer, and Peter Stone, editors, *Proceedings of the Fifth Workshop on Humanoid Soccer Robots in conjunction with the 2010 IEEE-RAS International Conference on Humanoid Robots*, Nashville, TN, USA, 2010.
19. N. Henderson, R. King, , and S.K. Chalup. An automated colour calibration system using multivariate gaussian mixtures to segment hsi colour space. In *Proc. of the 2008 Australasian Conference on Robotics and Automation*, 2008.
20. N. Henderson, R. King, and R. H. Middleton. An application of gaussian mixtures: Colour segmenting for the four legged league using hsi colour space. In *RoboCup Symposium, Atlanta, July 2007*, Lecture Notes in Computer Science, 2007.
21. Kenny Hong, Stefan Chalup, and Robert King. Affective visual perception using machine pareidolia of facial expressions. 2014.
22. Kenny Hong, Stephan Chalup, and Robert King. A component based approach for classifying the seven universal facial expressions of emotion. In *IEEE Symposium on Computational Intelligence for Creativity and Affective Computing 2013*. IEEE, 2013.
23. Kenny Hong, Stephan K. Chalup, and Robert King. Scene perception using pareidolia of faces and expressions of emotion. In *IEEE Symposium on Computational Intelligence for Creativity and Affective Computing 2013*. IEEE, 2013.
24. Arash Jalalian, Stephan K. Chalup, and Michael J. Ostwald. Agent-agent interaction as a component of agent-environment interaction in the modelling and analysis of pedestrian visual behaviour. In *CAADRIA 2011. Circuit Bending, Breaking and Mending. The 16th International Conference of the Association for Computer-Aided Architectural Design Research in Asia*, 2011.

25. J. Kulk and J. Welsh. Perturbation sensing using proprioception for humanoid robots. In *Proceedings of the IEEE Conference on Robotics and Automation*, 2010.
26. J.A. Kulk and J.S. Welsh. A low power walk for the nao robot. In *Proc. of the 2008 Australasian Conference on Robotics and Automation (ACRA'2008)*, 2008.
27. J.A. Kulk and J.S. Welsh. Autonomous optimisation of joint stiffnesses over the entire gait cycle for the nao robot. In *Proceedings of the 2010 International Symposium on Robotics and Intelligent Sensors.*, 2010.
28. Jason Kulk and James Welsh. Evaluation of walk optimisation techniques for the nao robot. In *IEEE-RAS International Conference on Humanoid Robots*, 2011.
29. M. Metcalfe, J. Fountain, A. Sugo, T. Houliston, A. Buddulph, A. Dabson, T. Johnson, J. Johnson, B. Annable, , S. Nicklin, S. Fenn, D. Budden, J. Walker, and J. Reitveld. Nubots robocup code repository. `https://github.com/nubots/NUClearPort`, January 2014.
30. S.P Nicklin, R. Fisher, and R.H. Middleton. Rolling shutter image compensation. In *Robocup Symposium 2006*, 2007.
31. M. J. Quinlan, S. K. Chalup, and R. H. Middleton. Techniques for improving vision and locomotion on the aibo robot. In *Australian Conference on Robotics and Automation (ACRA'2003)*. ARAA (on-line), 2003.
32. M.J. Quinlan, S.P. Nicklin, N. Henderson, Fisher R., F. Knorn, S.K. Chalup, R.H. Middleton, and R. King. The 2006 nubots team report. Technical report, School of Electrical Engineering and Computer Science, The University of Newcastle, Australia, 2006.
33. Josiah Walker and Stephan K Chalup. Learning nursery rhymes using adaptive parameter neurodynamic programming. In *Artificial Life and Computational Intelligence*, pages 196–209. Springer, 2015.
34. L. Wiklendt, S. K. Chalup, and M. M. Seron. Simulated 3d biped walking with and evolution-strategy tuned spiking neural network. *Neural Network World*, 19:235–246, 2009.
35. Aaron S. W. Wong, Stephan K. Chalup, Shashank Bhatia, Arash Jalalian, Jason Kulk, Steven Nicklin, and Michael J. Ostwald. Visual gaze analysis of robotic pedestrians moving in urban space. *Architectural Science Review*, 55(3):213–223, 2012.
36. Aaron S.W. Wong, Kenny Hong, Steven Nicklin, Stephan K. Chalup, and Peter Walla. Robot emotions generated and modulated by visual features of the environment. In *IEEE Symposium on Computational Intelligence for Creativity and Affective Computing 2013*. IEEE, 2013.